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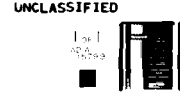

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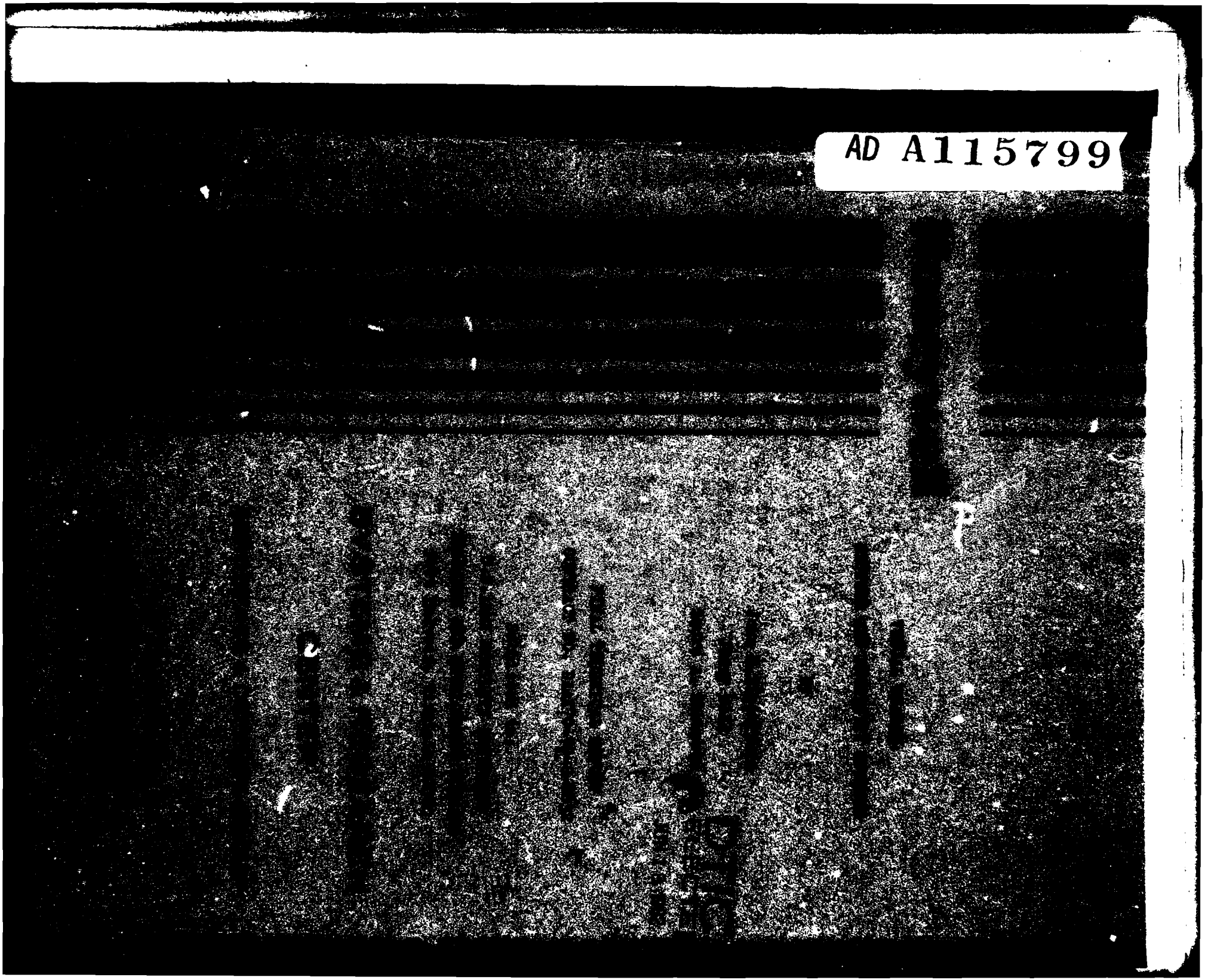

VISUAL SEARCH:
CLUTTER AND PROXIMITY EFFECTS

by

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FINAL TECHNICAL REPORT

on

Contract Number DAAK70-79-C-0032

Submitted to

U.S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND
Fort Belvoir, Virginia 22060

Honeywell Inc.
Systems and Research Center
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Minneapolis, Minnesota 55413

PREFACE

This final report is submitted to the U. S. Army Mobility Equipment Research and Development Command under contract number: DAAK70-79-C-0032.

We wish to thank Dr. Kenneth Oscar for his advice and encouragement.

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INTRODUCTION AND OVERVIEW

The objective of the experimental program proposed in this report is to explore clutter and texture effects and to determine their usefulness as camouflage aids. Several perceptual experiments were conducted. The data from them can be used to help characterize the relation between a military target and its detectability in complex backgrounds. Such work in perception is a necessary step toward the development of camouflage standards for the prime visual threat.

This work began under MERADCOM Contract No. DAAK70-77-C-0056, when Bloomfield, Wald and Smith (1978) investigated complex embedded target situations. Using the experimental stimuli of Bloomfield's (1979) visual search and peripheral acuity study, they measured discriminability by systematically degrading the observer's view of the stimuli in various ways. They also began to explore the effect on the detectability of targets of varying the nontarget, or clutter, density.

In the next section of this report, a review is given of the effects on visual search performance of varying the number of nontarget stimuli present, along with the target, in the search area, and of varying the proximity of these nontargets to each other.

The effects of varying nontarget density and number, with search area constant, of varying number and area, with density constant, and of inversely varying density and area, with number constant, are described. Then, the derivation of the general square root relationship between search time and the number of nontargets is given. Various anomalous results are mentioned. Finally, proximity effects that sometimes run counter to the effects of number are described, and related to more general proximity effects found in non-search situations.

The experiments described in the remaining two sections of the report were conducted in order to further explore the effects of proximity and number. Three experiments are described in Section 3. In the first, the effect on target acquisition performance of searching one or two regions having the same nontarget density was investigated. In the second, the effect that the presence of a region that did not have to be searched had on the performance of observers searching an adjacent region having the same nontarget density was examined. And, the third was simular to the second, except that the region that did not have to be searched was not of the same nontarget density as the region that was searched. In the first two experiments, search times were significantly different; in the third, the main effect of the unsearched region appeared to be in influencing the search strategy of the observers.

Two experiments are described in Section 4. They both involved two-region displays in which the nontarget density was different in each region. In the first, the target was hidden in each region an equal number of times. This meant that the individual nontargets in the region of lower density were replaced by the target more often than those in the region of greater density. In the second experiment, the likelihood of the target replacing each nontarget in the display was equal whether they were in the regions of lower or higher density. In the second experiment, the likelihood of the target replacing each nontarget in the display were equal whether they were in the regions of lower or higher density. In this case, the target appeared more often in the higher density region. In both experiments, it proved to be very difficult to search two regions of different nontarget density and in the initial, practice trials there were many false alarms. As the first experiment progressed, the observers appeared to adjust their search strategies so that, by the seventh and eighth sessions, the observers conducted a relatively complete

survey of the low density region in which the targets were easier to find before switching to the more difficult medium density display. In the second of these experiments, two observers also tended to concentrate more on the easier, low density display. However, this strategy was in some respects less effective than that adopted by the other two observers. The latter concentrated more on the medium density display in which the target was more often to be found.

After the References Section, an appendix has been added. This gives a summary of an additional experiment, run under the current contract, in which we compared scores obtained with a direct electronic Fourier transform (DEFT) device with discriminability data obtained in a viewing distance experiment. The close agreement found between the DEFT measurements and the behavioral data suggested that more rigorous testing might be worthwhile.

The experiments reported have provided evidence of the effects of clutter and texture on target acqusition strategies and performance. The results fill a significant gap in our knowledge, and are a further step toward developing camouflage standards.

SECTION 2
NUMBER AND PROXIMITY EFFECTS IN DENSITY EXPERIMENTS

The three variables, nontarget density, number of nontargets, and relative size of the search area, are related in a complex way. One of them can be held constant, while the other two are varied: but two of them can not be held constant at the same time. When area is held constant, density and number vary together. When density is held constant, number and area vary together. In both cases, when one of the pair of variables increases or decreases, the other variable changes in the same way. However, when number is held constant, density and area have an inverse relationship: as the area decreases the density increases,and vice versa.

It is for these reasons that reports of density experiments should be examined carefully. The results obtained in experiments purporting to investigate one of these variables can, in fact, be attributed to two possible sources of variation. Only Drury and Clement (1978) have attempted to disentangle the three variables in a single experiment.

VARYING DENSITY AND NUMBER (AREA CONSTANT)

In many experiments, increasing the density and number of nontargets, with search area held constant, produces increases in search time. This is found when the target differs in shape from the nontargets (Eriksen, 1955; S. W. Smith, Kincaid and Semmelroth, 1962, Erickson, 1964), when it differs in size (Bloomfield, 1970), when it is a particular number in an array of digit combinations (Green and Anderson, 1956; McGill, 1960; S.L. Smith, 1962), and when it is a particular letter or letter combination in an array of letters (Williams and Borrow, 1963; Drury and Clement, 1978).

VARYING NUMBER AND AREA (DENSITY CONSTANT)

Increasing the number of nontargets and the search area, with nontarget density held constant, has a similar effect. Search time increases with the number of nontargets, whether the target differs in shape (Boynton, 1960; Baker, Morris and Steadman, 1960; Brody, Corbin, and Volkmann, 1960; Johnston, 1965), whether it is a number in other digits (Cizkova, 1967), a particular letter or letter pair in other letters (Cizkova, 1967; Drury and Clement, 1978), or whether it is specified in terms of a particular dial hand orientation in a background of other dials (Cizkova, 1967).

INVERSELY VARYING DENSITY AND AREA (NUMBER CONSTANT)

The effect of holding the number of nontargets constant and increasing nontarget density while decreasing the search area is less clear cut. Ericksen (1955) obtained inconsistent results, and suggest that it was probably an artifact of the way his observers were required to indicate that they had located a target. Baker, Morris and Steadman (1950) mention an experiment with area increased, number of nontargets held constant, and decreasing density. They found no resultant change in search time, but no details of this experiment were given. In contrast, Bloomfield, Beckwith, Emerick and Tei (1975), using targets differing in color mixture from the nontargets, found that search time increased as area increased and nontarget density decreased. Drury and Clement (1978) used letter stimuli and found that search time increased as the area increased from 100 to 400 degree^2, but decreased as it went one more step to 600 degree^2. This is an area where more work is still required.

RELATION BETWEEN SEARCH TIME AND THE NUMBER OF NONTARGETS

The relation between mean or median search time and the number of nontargets, with either density or area varied with number, appears to be roughly linear. However, S. W. Smith (1961) suggested that the relation might better be described by a power function.

Then with 't' as search time, and 'N' as the number of nontargets:

$$t = aN^m , \qquad \text{(equation 1)}$$

where 'a' and 'm' are constants.

This equation described quite well the data of Green and Anderson (1956), McGill (1960), and Brody, Corbin and Volkmann (1960, as well as S.W. Smith's own data.

S.W. Smith, Kincaid, and Semmelroth (1962) suggested that, while the power function describes the relationship well when the target and nontargets differ on a single dimension, it is less adequate when they differ on more than one dimension; for example, when they differ in contrast and shape.

When the extensive data of S.W. Smith, Kincaid, and Semmelroth (1962) are plotted on logarithmic axes, the straight line fit obtained (and shown in Figure 1) supports equation 1. The gradient of this line is 0.49. And, as Bloomfield (1970) pointed out, this suggests that there is, in fact, a square root relationship between search time and the number of nontargets. Figure 2 replots the S.W. Smith et al. data, showing the square root relationship quite clearly: search time is proportional to the square root of the number of nontargets.

Bloomfield (1973), using a target that differed in size from the nontargets it was among, found that not only was there a square root relationship when mean or median search times were used, but that this square root relationship held over the complete distribution of search times from which the mean or median was derived.

ANOMALOUS DATA

Anomalous results, that are not in accord with this square root relation, have been obtained in two different types of experiment: both when the number of nontargets immediately surrounding the target were varied while the overall

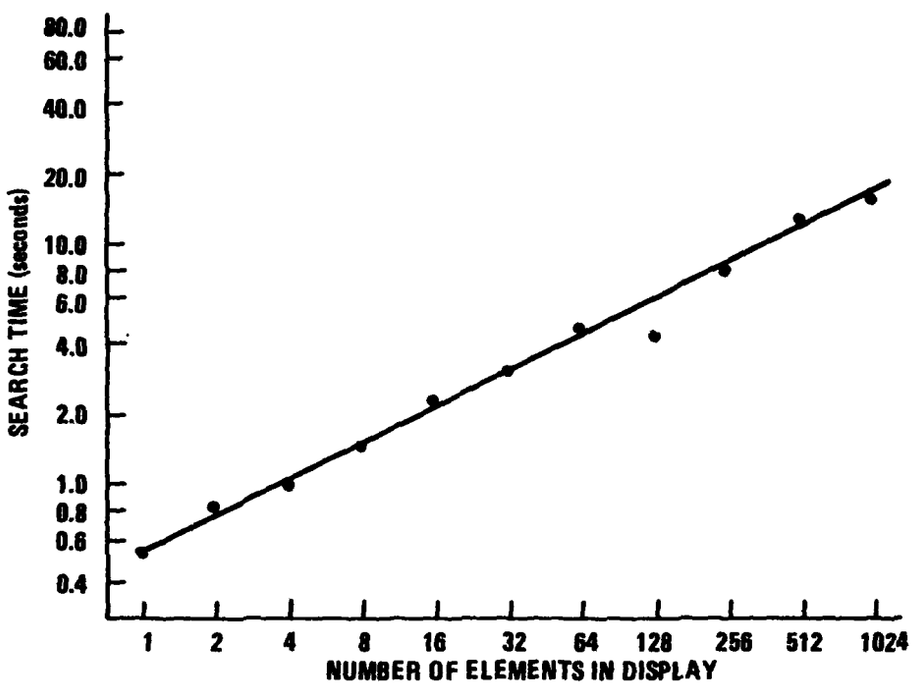

Figure 1. Log-log plot of mean time to locate a square target as a function of the density (and number) of nontarget discs (from Smith, Kincaid, and Semmelroth, 1962).

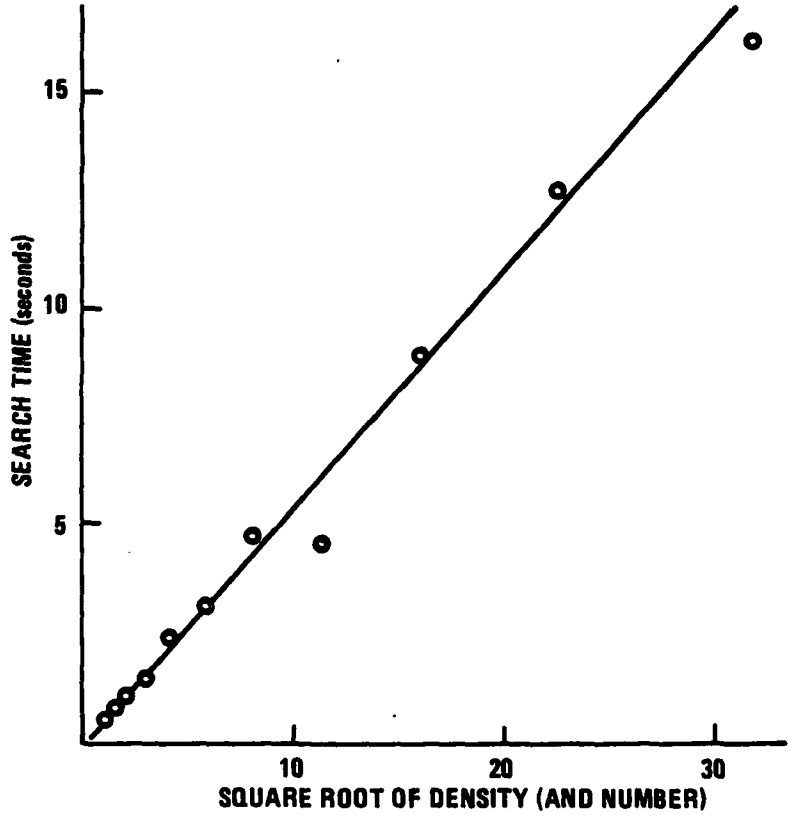

Figure 2. Data from Figure 1 replotted as a function of the square root of the density (and number).

number of nontargets in the search area was held constant (Brown and Monk, 1975; Monk and Brown, 1975), and when the density of the nontargets was taken to the limit where the nontargets were so dense that they touched each other and the display became an embedded target display (Bloomfield, Beckwith, Emerick, and Tei, 1975).

PROXIMITY EFFECTS

Data from this latter experiment, by Bloomfield, Beckwith, Emerick, and Tei (1975), are shown in Figure 3. For one target (white), the square root relationship holds for all displays, except the limiting density display. For this last display, where the target is embedded in the nontarget background, the search time is considerably smaller. For the second target (tan), the curve is U-shaped. At first, search time increases as the number of nontargets increases. It then remains roughly constant, before decreasing as the limiting density condition is approached.

There appears to be a proximity effect that runs counter to the effect of increasing the number of nontargets. And, this proximity effect appears to vary with the particular stimuli that are involved.

Human perception does not depend simply upon absolute values, like the color, temperature, intensity of the reflected light, and size of a stimulus. It also depends upon relationships. A particular surface may be perceived differently as a function of changes in the color, contrast or texture of an adjacent surface area. What an observer "sees" depends both on the physical characteristics of the surfaces being observed, and of subjective, perceptual interaction effects induced by the surfaces. The Mach band effect, which was first pointed out in 1865 (see Mach, 1914), is an often commented upon, induced, perceptual effect. Albers (1963) produced several striking color interaction effects.

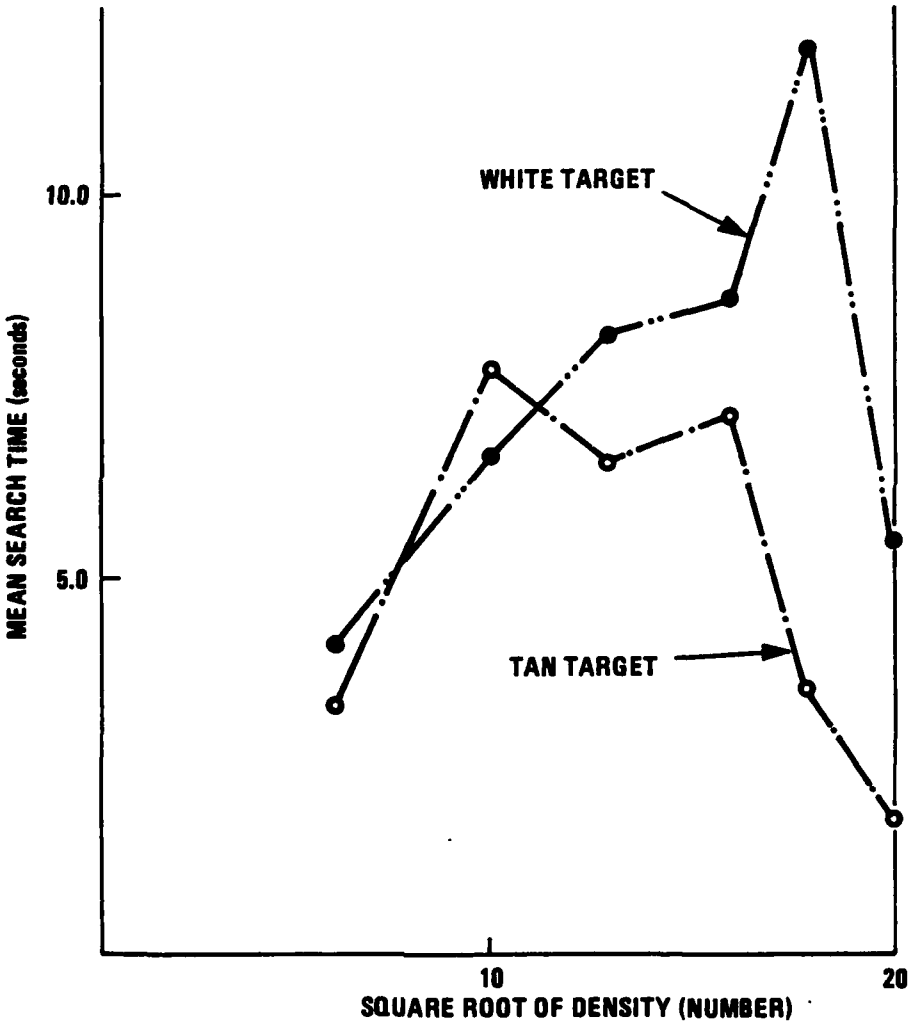

Figure 3. The relationship between mean search time and the density (and number) of nontargets, as density is increased to the limit (from Bloomfield, Beckwith, Emerick, and Tei, 1975).

The presence of an adjacent area may affect more than the perception of a particular area. It may also affect the ease with which a target can be detected in that particular area.

The experiments carried out under contract number DAAK70-79-C-0032 were conducted in order to further explore the effects of proximity and nontarget number on search performance. Some preliminary results, obtained with a pilot subject were reported earlier by Bloomfield, Wald and D.A. Smith (1979). More extensive experimentation was carried out under the current contract. This is reported in the rest of this document.

SECTION

3

VISUAL SEARCH IN TWO-REGION CLUTTER DISPLAYS

INTRODUCTION

In previous experiments investigating the effects of variations in nontarget density and number, the observer has been presented, typically, with a search display containing a single well defined region. In the three experiments described in this section, displays with two distinct regions were used. The effect of varying the number and density of nontargets when more than one well defined region has to be searched or when a region that has to be searched is adjacent to another region that does not have to be searched, was investigated in these experiments.

In the first experiment, the effect on target acquisition performance of searching one or two regions having the same nontarget density was investigated. In the second, the effect of the presence of a region that did not have to be searched on the ability of observers to search an adjacent region having the same nontarget density was examined. And, in the third, the effect of having an adjacent nonsearched region that differed in density from the region being searched was explored.

EXPERIMENT 1: SEARCH PERFORMANCE WITH ONE OR TWO SEARCH REGIONS

Method

Observers. Four observers participated in the experiment. They were between 16 and 35 years of age. Each had normal color vision and a Snellen acuity (with correction, if necessary) of 20/20 or better in each eye. They were paid for their participation at the conclusion of the experiment.

Displays. The displays were prepared using the same commercially available vinyl asbestos tiles that Bloomfield, Beckwith, Emerick and Tei (1975) used. Here, two types of tile were used. They were similarly patterned with small patches of color, but they differed in the range of colors they contained. For convenience, they are referred to here by the name of their dominant hue, yellow or white. The various colors present on the tiles were specified, using the glossy collection of the Munsell color system, with the results shown in Table 1.

Dominant Hue of Tile	Color of Patches	Munsell Color Notation	
		Hue	Value/Chroma
Yellow	Deep yellow	3.5Y	5.4/6.8
	Yellow	3.5Y	7.2/6.4
	Dark grey brown	3.0Y	7.2/2.4
	Light grey brown	4.0Y	7.8/1.2
	White	10.0Y	8.6/1.2
White	Cream	7.5Y	8.8/1.4
	Tan	1.5Y	6.2/4.4
	Brown	8.0YR	4.8/4.4

Table 1: Munsell color notation for patches of color on vinyl tiles used for displays (Adapted from Bloomfield, 1979).

Nontarget squares, each 2.54cm by 2.54cm were cut from the yellow tiles and backed with magnetic tape. Targets were prepared in the same way, using a white tile.

Six display boards were prepared. They were cut from aluminum sheets and printed with grey magnetic paint. Three boards were 54.62cm x 81.93cm, and three were 54.62cm x 41.28cm. Yellow nontarget squares of tile were mounted in a 47.00cm x 36.20cm region of the smaller boards. The larger boards contained two similarly-sized regions, with a 4.45cm gap between them. High, medium, and low density displays were produced by varying the number of nontargets in the regions. For the high density, there were 221 nontargets, arranged in a regular 17x13 array. For the medium, 63 nontargets were arranged in a 9x7 array. And, for the low, 20 nontargets were in a 5x4 array. In this experiment, both regions on the larger boards had the same nontarget density.

Apparatus Each observer sat in a darkened room 0.91m. from the center of a two-way mirror. The mirror was oriented at a 45^{0} angle relative to the observer's line of sight. The display board was 0.91 beyond the mirror on the line of sight.

On both sides of the mirror there were four lamps containing 100w. bulbs. The lamps on the observer's side of the mirror were pointed at right angles to the observer's line of sight toward a blank field. When they were illuminated, the blank field was reflected in the mirror. The lamps on the display board side of the mirror were directed along the observer's line of sight so that they would illuminate the display board. The electrical arrangement of the lamps was such that when one set of four were on the other set were off, and vice versa. The lamps were adjusted so that the levels of illumination provided on both sides of the mirror were approximately equal and, when the lights on one side were switched on and those on the other were switched off, the apparent brightness of the display or the blank field did not change.

A cover for this apparatus was constructed from heavy black fabric. When it was in place the apparatus was shielded from stray light.

Procedure. Each observer was tested individually. During each experimental session, the observer searched six display boards - one for each combination of board size (large or small) and nontarget density (high, medium or low).

In order to provide a balanced randomized order of presentation for the six display boards, a 6x6 Latin square was used. With this, the order of presentation was randomized within each session, but balanced across each block of six sessions. A different Latin square was used for each observer. The Latin squares were selected to satisfy the constraint that each board should not directly precede or follow any other board more than once in the block of six sessions.

Typically, unpracticed observers improve from one session to another. The four observers used here were no exception. Because of this, the initial sessions were treated as practice sessions. After the session-to-session performance stabilized, six more sessions were conducted. The observers took part in two, three or four practice sessions. In order to preserve the balanced random order in the final six sessions, the order for session 1 was repeated for session 7, that for session 2 was repeated for 8, and so on. No observer had more than four or less than two practice sessions.

During each session, there were ten search trials with each display board. There was a brief break for the observer between the blocks of trials, while the experimenter switched boards. There was also a ten-minute break in the middle of the session, after three of the boards had been presented. Each session lasted approximately 90 minutes.

Before each trial, while the blank field was being illuminated, the experimenter removed one of the yellow nontargets from the display board and replaced it with a white target. The target positions had been selected randomly, with replacement, before each session.

Trials were initiated when the observer pressed a switch which (1) turned off the lamps illuminating the blank field, (2) turned on the lamps illuminating the display, and (3) started an electric timer. When the observer located the target, he or she released the switch, reversing the lighting and stopping the timer. Then, to indicate the location of the target, the observer pointed to a grid positioned below the line of sight. The experimenter recorded the search time, and told the observer what it had been, after each trial. If the observer incorrectly indentified a nontarget as the target, the trial was repeated using the same target in another randomly chosen position.

Results

False alarms. There were more occasions when a nontarget was incorrectly identified as a target in the early practice sessions than there were in the experimental sessions that followed them. During practice, between them, the four observers had 76 false alarms. These false alarms occurred in 796 trials, giving a false alarm rate of 9.5%. This rate dropped to 3.9 during the experimental sessions, with 59 false alarms occcuring in 1,499 trials.

More false alarms occurred with the two-region display (13.5% in practice, 4.9% in the experimental sessions) than with the one-region display (5.3% practice, 3.0% experimental sessions).

Cumulative search time distributions. Data from the last six sessions of the four observers were plotted in the form of cumulative search time distributions. A typical plot for observer, S1, is shown in Figure 4. Similar graphs were obtained for the other three observers.

Effect of varying nontarget density. In order to determine whether the cumulative distributions obtained with high, medium and low nontarget density displays were significantly different from each other, a series of Mann-Whitney U tests were conducted. Table 2 shows the results of these test comparisons for the one- and two-region displays for all four observers.

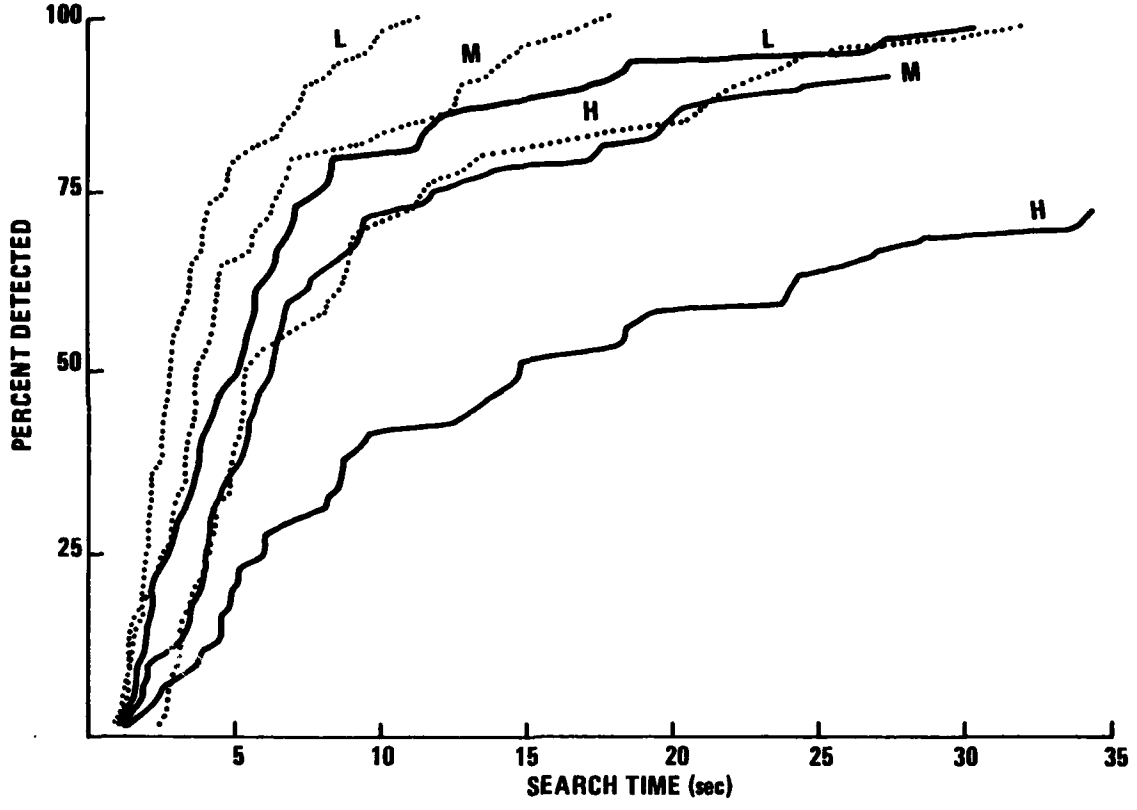

Figure 4. Cumulative distribution of search times for observer S1 searching for a target in one ...., or two——, low (L), medium (M), or high (H) nontarget density regions.

	One-Region Displays			Two-Region Displays		
Observer	Low v. Medium	Low v. High	Medium v. High	Low v. Medium	Low v. High	Medium v.High
S1	.05	.001	.001	.05	.001	.001
S2	.05	.001	--	--	.01	.05
S3	.001	.001	.05	.001	.001	.01
S4	.05	.001	.001	.01	.001	.001

Table 2: Level of significance, obtained with Mann-Whitney U test, of differences between cumulative search time distributions obtained with low, medium, and high nontarget density displays for four observers searching both one- and two-region displays.

Table 2 shows that the search time distributions obtained with high, medium and low nontarget density displays are significantly different.

Effect of searching one- or two-regions. The Mann-Whitney U test was also used to compare the search time distributions obtained with the one- and two-region displays. Table 3 shows the results of these comparisons for each level of nontarget density for all four observers. Table 3 makes it clear that the differences in search times for the one- and two-region displays that are demonstrated in Figure 4 are statistically significant.

	Comparison of One v Two Regions For		
Observer	Low Density	Medium Density	High Density
S1	.001	.001	.001
S2	.001	.05	.01
S3	.001	.001	.001
S4	.01	.001	.001

Table 3: Level of significance, obtained with Mann-Whitney U test, of differences between cumulative search time distributions obtained with one- and two-region displays for four observers searching displays of three different nontarget densities.

Discussion

The displays used in this experiment had some similarities with those used by Bloomfield, Beckwith, Emerick and Tei (1975). The nontargets were the same, and the white target used here was one of those used before. The new nontarget density levels were similar to those in the 6x6, 10x10 and 18x18 arrays of the earlier study, although the actual number of stimuli and the dimensions of the array of nontargets differed. The limiting nontarget density was not included as one of the conditions in the current experiment. As before, as nontarget density increased up to (but not including) the limiting condition, the time needed to locate the white target increased.

The effect of increasing the area and the number of nontargets was also investigated. Here, the area and number were doubled by using a display with two distinct regions, whereas in previous studies (cited in the previous section of this report) a single region of varying size was used. However, the effect was the same: search time increased with increasing area and number.

This experiment was conducted to provide a base line comparison for subsequent experiments carried out as part of this project.

EXPERIMENT 2: SEARCHING ONE REGION IN THE PRESENCE OF A SECOND REGION OF SIMILAR NONTARGET DENSITY

This experiment was identical to Experiment 1, except that when the observer was viewing the two-region display he or she was told in which region the target was to be found, and was instructed to search that region and not the other.

Method

The experimental method used for this experiment was essentially the same as that for the previous experiment. Because a detailed account of that method was provided earlier in this section of the report, only the divergencies from that method are noted here.

One of the four observers taking part in Experiment 2 (S3), had also participated in Experiment 1. The other three observers had no previous experience in experiments of this kind.

When searching the two-region displays each observer knew in which region, the right or left, the target could be located, and he or she was instructed to search only that region. In each session, the same side was used for

all three two-region displays. Then, the other side was used in the subsequent session.

Results

Cumulative search time distributions. Data from the last six sessions of the four observers used in Experiment 2 were plotted in the form of cumulative search time distributions. Data from one observer, S5, is shown in Figure 5. Similar graphs were obtained for S3 (who took part in Experiment 1 also), S6 and S7.

Effect of varying nontarget density. As before, a series of Mann-Whitney U tests were conducted in order to determine whether the cumulative search time distributions obtained with the high, medium, and low density displays were significantly different from each other. Table 4 shows the results of these comparisons. The search times obtained with the low nontarget density displays are significantly shorter than those obtained with the medium and high density displays. And, for three of the eight comparisons of medium and high density displays, the times obtained with the medium density displays are also significantly shorter.

Searching one region in the presence of a second region of similar nontarget density. The Mann-Whitney U test was used to compare the search time distributions obtained when one region was searched in displays with one region or with two. Table 5 shows the results of this comparison.

For three observers (S3, S5 and S7), the presence of a region that did not have to be searched, significantly affected performance for the low density condition. For the fourth observer (S6), there was an effect for the medium density condition. In all four cases, the effect was to increase search time when there was a second region containing nontargets present, even though it did not have to be searched.

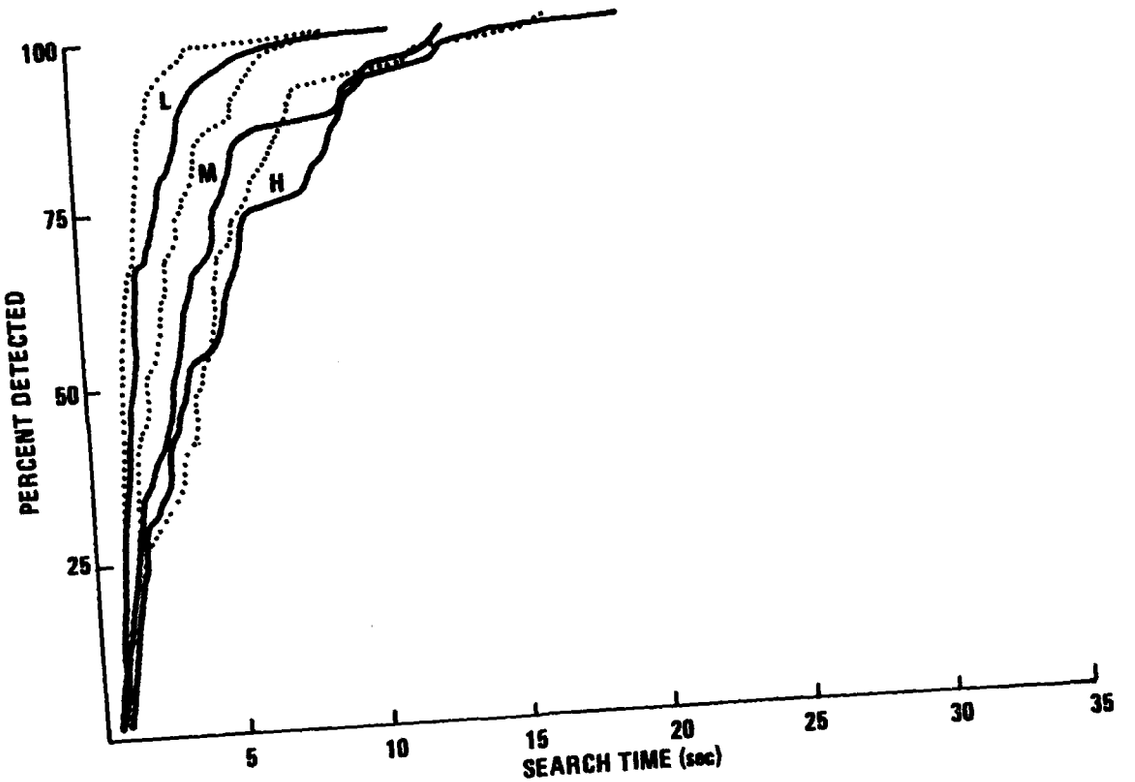

Figure 5. Cumulative distribution of search times for observer S5 searching for a target in a single low (L), medium (M), or high (H) nontarget density region presented alone ...., or in the presense of a second region of similar density ——.

	One-Region Display			Two-Region Display		
Observers	Low v. Medium	Low v. High	Medium v. High	Low v. Medium	Low v. High	Medium v. High
S3	.001	.001	--	.001	.001	--
S5	.001	.001	.05	.001	.001	.01
S6	.001	.001	.100	.001	.001	--
S7	.001	.001	--	.01	.01	--

Table 4. Level of significance, obtained with Mann-Whitney U test, of differences between cumulative search time distributions obtained with low, medium, and high nontarget density displays for four observers searching one region in both one-region and two-region displays.

	Comparison of Searching One Region Presented (a) Alone, (b) in Presence of Another Region		
Observer	Low Density	Medium Density	High Density
S3	.05	---	---
S5	.01	---	---
S6	---	.05	---
S7	.05	---	---

Table 5. Level of significance, obtained with Mann-Whitney U test, of differences between cumulative search time distributions obtained when four observers searched one region of one- and two-region displays of three different nontarget densities.

Discussion

As in the previous experiment, as nontarget density increased towards, but not including, the limiting condition, the time needed to locate a white target amongst yellow nontargets increased.

The presence of a region containing nontargets, but not containing a target, did influence the time needed to find a target in another region. For three observers, this influence occurred when the density of nontargets in the two regions was low. For the fourth observer, it occurred when there was a medium nontarget density.

EXPERIMENT 3: SEARCHING ONE REGION IN THE PRESENCE OF A SECOND REGION OF DIFFERENT NONTARGET DENSITY

There were many similarities between this experiment and Experiment 2 described above. Here the objective was to discover whether or not the ability of an observer to find a target in a particular region was affected by the presence of an adjacent region containing nontargets, when the density of those nontargets was different in the two regions.

Method

Many details of experimental method were the same in this experiment as they were in the previous one. Because of this, an abbreviated account of the method is provided here.

Observers. Six observers participated in Experiment 3. Three of them had taken part in either Experiment 1 or 2. All were between 19 and 29 years of age. Each observer had normal color vision and a Snellen acuity of 20/20 or better in each eye. They were paid for their participation.

Displays. The same targets and nontargets as were used in Experiments 1 and 2 were used again. Two displays were used. Both were two-region displays. In the first, one region was of medium nontarget density while the other was of low nontarget density. In the second, one region was again of medium density while the other was of high density.

Apparatus. The apparatus and experimental set up were as described for the previous two experiments.

Procedure. Each observer was tested individually. Only the medium density regions of the display boards were searched. For three observers (S1, S9, S10), the medium density region always appeared on the left side of the display, with the high or low density region appearing on the right. For the other three observers (S5, S6, S8), the medium density region was always on the right, with the high or low density on the left.

The order in which the two boards were searched was counterbalanced across sessions. In each session, there were 31 trials with the first-board used, and 32 with the second. Within each two-session cycle, for both the display with the unsearched, high-density region and the display with the unsearched, low-density region, there were 63 trials. The medium density region has a 9 x 7 arrangement of nontargets. Each position on this grid was used once in each two-session cycle. The positions were sampled randomly, without replacement.

When nontargets were incorrectly identified as targets in this experiment, the trial was repeated with the target occurring in the same location in the grid at a randomly determined time in the same block of trials.

Each observer took part in 10 or 12 sessions. Each session lasted approximately 90 minutes.

Results

Cumulative search time distributions. Data from the last six sessions of the six observers were plotted in the form of cumulative search time distributions for each of the two displays. The two distributions obtained for each observer were compared using the Mann-Whitney U test. For five observers, the distributions were not significantly different. For the sixth (S9), the search times obtained when the adjacent region was of lower nontarget density were significantly faster (at the .002 level) than those obtained when it was of higher density.

Position analyses. Column-by-column and row-by-row analyses were conducted for both displays for each observer. The geometric mean of the search times obtained for each row and each column were calculated. For each observer, each row mean is based on 21 trials and each column mean on 29: these means are plotted in Figures 6 and 7, respectively.

Discussion

For five observers (S1, S5, S6, S8, and S10) the overall cumulative search time distributions were not significantly different. For the sixth observer (S9), search times were longer when the medium density region that was being searched was next to a high density region.

An examination of the row-by-row data of Figure 6 shows that very different curves were obtained from the six observers. The differences do not seem to be related to the side of the display on which the region to be searched was located. This region was on the right side for S5, S6, and S8. For S5, the times are shortest for the center rows and longer for those at the top and bottom of the search region. On the other hand, for S6, the differences between rows are small and the mean times are in general very low. While

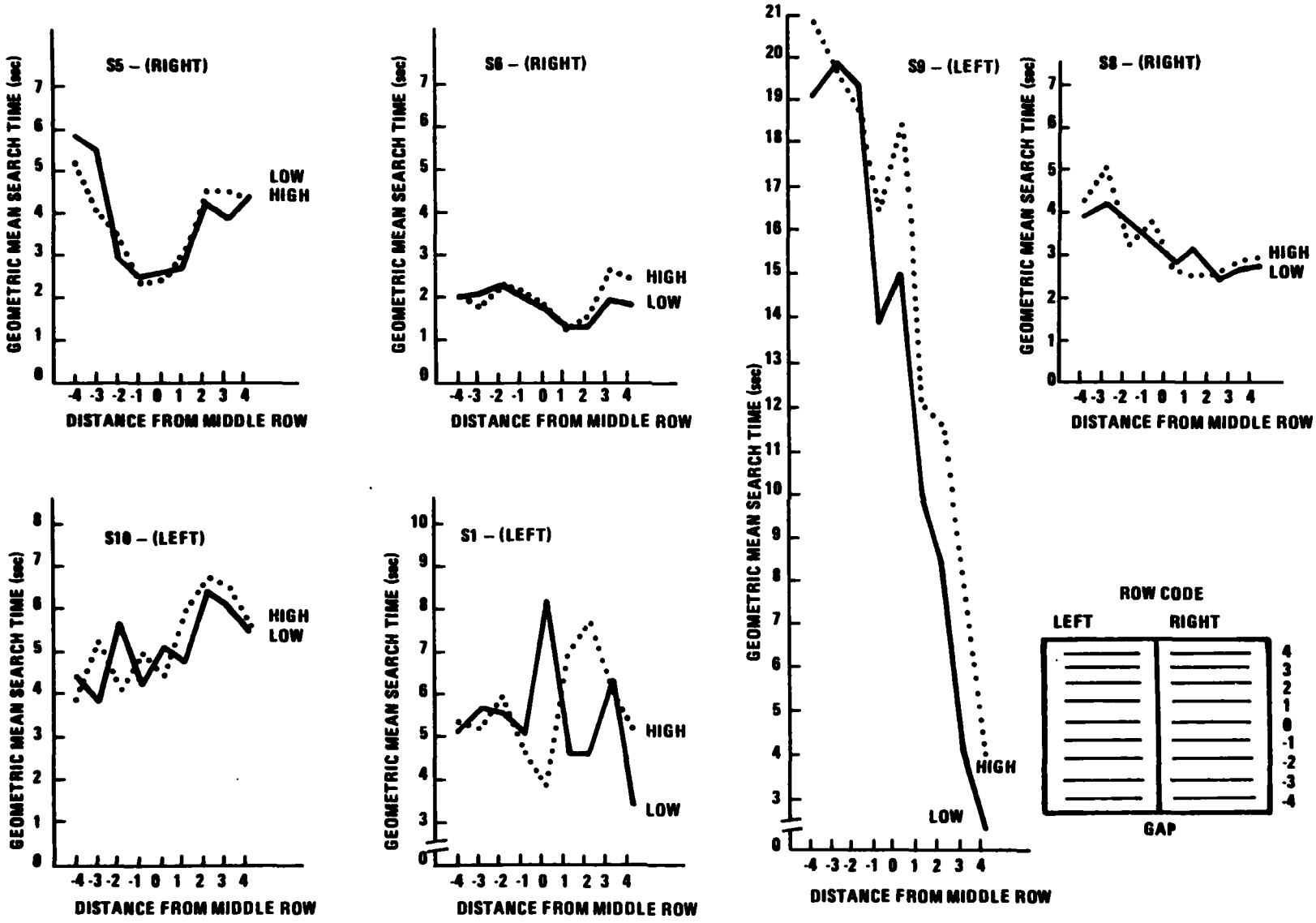

Figure 6. Row means for six observers searching the medium density region of a two-region display when the second region is of high or of low density.

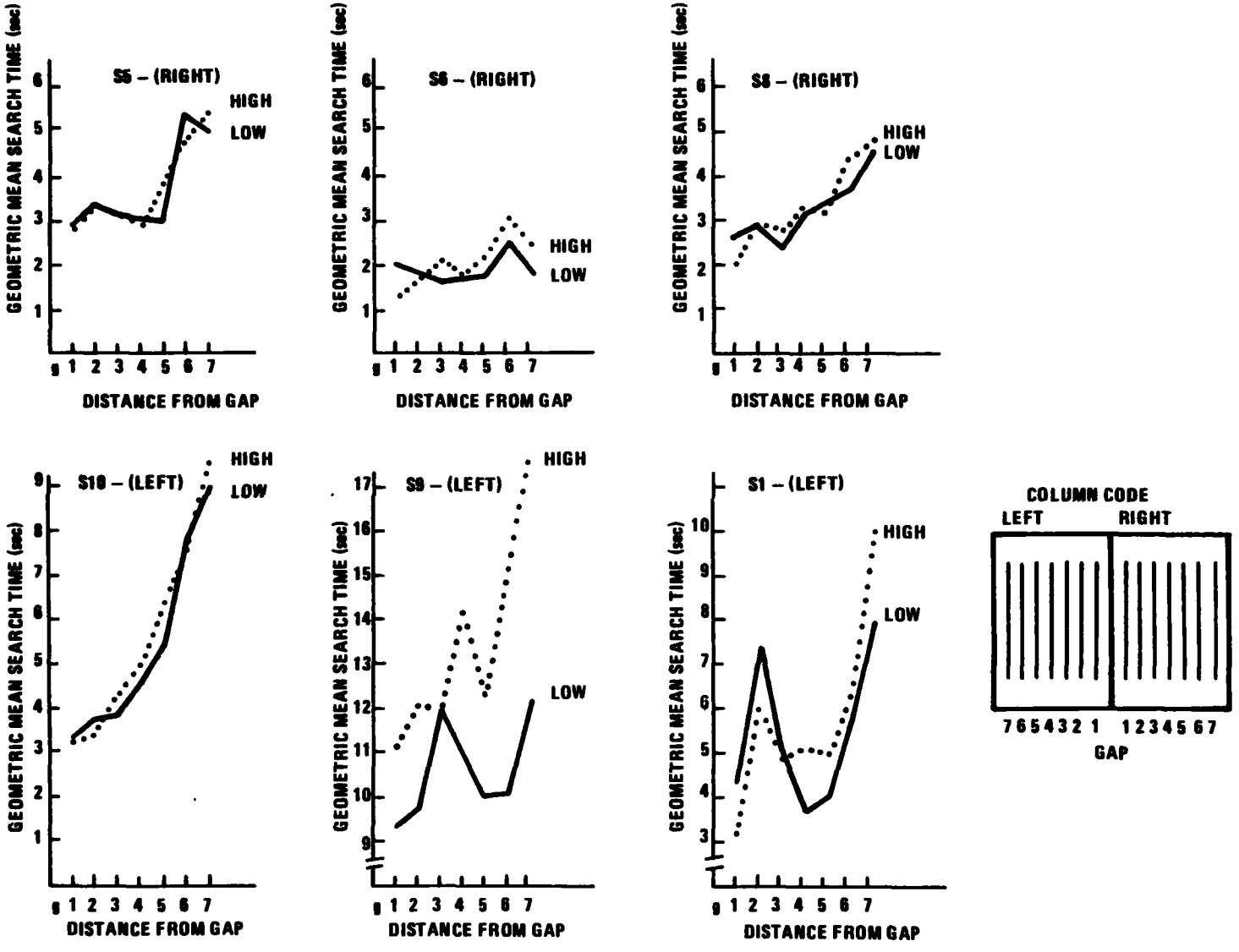

Figure 7. Column means for six observers searching the medium density region of a two-region display when the second region was of high or of low density.

for S8, the times are shortest for the upper part of the region and progressively longer for the lower rows. There are also differences between observers S1, S9, and S10 who had the search region on the left side. There is considerable variability in the means for S1, but in general rows at the top seem to have been searched quicker than those at the bottom of the region. For S9, there is an enormous row effect with mean times for the upper rows being relatively short (three to four seconds) then progressively lengthening until they are 19 or 20 seconds for the bottom rows. For S10, the times for the bottom rows are fastest, while those for the upper rows are longer.

Given the variability in Figure 6, one might expect the column-by-column analysis to produce similar variability. However, as observation of Figure 7 shows, there are indications that for all six observers, the search times were shorter for the columns next to the unsearched region, whether it was on the left or the right. For two of the three who searched the right side only (S5, S10), search times are shorter for columns nearest to the unsearched region than they are for columns furthest away from it. This pattern is harder to see for S6, who found the targets faster than the other observers, however, it can be seen for the case when the unsearched region is of high nontarget density. For all three observers who searched the right side only, the times are shortest for the columns nearest to the unsearched region. The effect can be seen, in spite of some variability in the data, for S1 and S9, and is quite clear and unambiguous for S10.

Although as Figure 6 indicates, the observers used different search patterns, the presence of an adjacent region containing a number of nontargets did influence the way the observers searched, so that search times were relatively short when the target was placed in a column close to the adjacent region.

With the exception of S9, there was no significant difference in overall search time distributions whether the adjacent region was of high or low nontarget density. From this, one should not assume that the density of

the nontargets in an adjacent region is irrelevant, simply that the effects of the two densities chosen here are not distinguishable from each other. It is clear that more experimental work is needed to explore the effects of nontarget density and adjacency on visual search performance.

SECTION 4
SEARCHING BOTH SIDES OF A TWO-REGION DISPLAY

INTRODUCTION

The first experiment in the previous section was conducted in order to compare search times obtained when observers searched one or two identically-sized regions of the same nontarget density. The search times obtained when the two distinct regions were searched were much like those obtained when the search area is simply doubled.

In the experiments reported here, we wanted to investigate what happened when the two regions had different densities of nontarget.

Two experiments were carried out. In the first, it was equally likely that the target would be in one region as it was that it would be in the other. This meant that it would replace particular nontargets in the low density region more often than those in the high density region. In the second experiment, the chances of the target replacing each nontarget were the same. This meant that the target occurred more often in the higher density region.

EXPERIMENT 4: SEARCHING BOTH SIDES OF A TWO-REGION DISPLAY WHEN THE TARGET IS EQUALLY LIKELY TO BE ON EITHER SIDE.

Method

Observers Three observers between 21 and 31 years of age completed this experiment (S12, S13 and S14). They all had normal color vision and a Snellen acuity (in some cases with correction) of at least 20/20 in each eye. None had taken part in a search experiment before. Each was paid for their participation in the experiment.

A fourth observer (S11) also participated in, but did not complete this experiment. For this observer the task proved to be very difficult. The search times obtained were longer than usual and there was a false alarm rate of over 50% throughout the first three sessions. Even when the session length was increased, it was not possible to complete all of the trials planned for a session. By mutual agreement, this observer did not continue the experiment.

Displays. As with the experiments reported in the previous section, the displays were prepared using the squares of vinyl asbestos tile used by Bloomfield, Beckwith, Emerick and Tei (1975). Also, as before the dominant hue of the nontargets was yellow, while that of the targets was white.

The yellow nontarget squares were placed on two aluminum display boards which were coated with grey magnetic paint. Both display boards had two regions within which the nontargets were positioned. There was a 4.45 cm gap between the regions. A 5x4 array of nontargets was placed in one region, the low density region, and a 9x7 array was placed in the other, the medium density region. The two boards were differentiated by the labels No. 1 and No. 2 being placed on the back of each.

Apparatus. Each observer sat 0.66 m. from the center of a half-silvered mirror. The mirror was on a table and at a 45^{0} angle to the observer's line of sight. Four 100w bulbs were placed in high intensity dimmer lamps on either side of the mirror. The display board was mounted 1.17m. behind the mirror perpendicular to the observer's line of sight.

The lamps on the observer's side of the mirror were positioned so that they provided approximately even illumination of a blank field to the observer's left. Like the display, the blank field was 1.17m. from the center of the mirror: consequently, no change in the accommodation of the observer's eyes was necessary when switching from the blank field to the display and back again. The lamps on the display side of the mirror were

adjusted to provide approximately even illumination over the two regions. The two sets of lamps were adjusted until the perceived brightness of the display was the same as that of the blank field, when the switch was operated. Heavy black fabric was draped over the experimental set-up to eliminate stray light.

Procedure. The observers were tested individually in sessions that lasted approximately 1.5 hours. One observer (S12) took part in six sessions, while the other two (S13, S14) were in eight.

The No. 1 display was used in the first half of each session, and the No. 2 display was used in the second. Whether the low density region appeared on the left or the right side of the display No. 1 and on the right or left for display No. 2 was determined randomly for each observer for the first session, and then counterbalanced across sessions. In order to avoid any individual target effects, five different white target squares were used as targets. They were used an equal number of times in each session in a randomly selected order.

The order in which the target was placed in the low or medium density regions was determined randomly, without replacement. The target appeared an equal number of times in each region in each half of the sessions. The target position within a region was also determined randomly, but this time with replacement.

The observers were informed that there was a fifty percent chance of the target being located on either side of the board; that, even though there were more nontargets in one region than the other, the target was equally likely to be found in either.

Before each trial, the experimenter removed a nontarget and replaced it with a target. Then, the observer operated a switch. This simultaneously turned off the lights on the blank field side of the mirror, turned on those on the display side, and started an electric timer. The observer

then indicated the position in which he or she thought the target was located. The time to respond was recorded. If the target was correctly located, the observer was informed of the search time. During the early practice sessions, if a nontarget was incorrectly identified as a target, the observer was given a second look at the display and the experimenter indicated the position in which the target was located. During the experimental sessions, however, if this occurred the observer was told it was a false alarm but was not shown the display again.

There were forty trials per session, twenty with each board, with a ten-minute break in between.

In order to prevent the observer from remembering which nontarget positions were particularly hard or easy to confuse with the target, a number of randomly selected nontargets from both regions were interchanged between sessions.

Results

False alarms. The task of searching two regions of different nontarget density proved to be very difficult. One observer, S11, had 26 false alarms, out of a possible 40 trials, in the first session. This false alarm rate dropped in the two subsequent sessions, but, when this observer stopped after the third session, 63 out of 120 trials had resulted in false alarms.

A second observer (S12) also had more than fifty percent of the search trials end in false alarms in the first session. However, the number dropped to more acceptable levels as the experiment progressed. The percentage of false alarms for this observer over six sessions was 55, 32.5, 22.5, 7.5, and 7.5%.

The other two observers had fewer false alarms. S13 had nine false alarms in the first session and three in the second. However, in the remaining seven sessions in which S13 took part there were four with only one false alarm and three with none.

The fourth observer, S14, had fewer false alarms: 7 out of 120 in the first three sessions, only one in the fourth, and none in the last five sessions.

Cumulative search time distributions. The first three sessions were treated as practice. Data from the fourth, fifth and sixth sessions, were combined to produce cumulative plots of the time needed to locate targets in the low density region and the medium density region, for the three observers who completed the experiment. Figure 8 shows the distributions for S14. Those for S13 were similar, while the difference in distributions was even larger for S12, who generally speaking, found the search task harder than S13 and S14. When the distributions were compared, using the Mann-Whitney U test, they were found to be significantly different at the .0001 level, for all three observers.

Observation of the data from individual sessions showed that, although some relatively large learning effects had been eliminated by treating the first of those sessions as practice, there were still some session-to-session improvements. Two observers were asked to continue with the experiment in two additional sessions. Cumulative plots were made of the data from these two sessions for those observers, S13 and S14. Figure 9 shows the results for S14. The data from S13 is similar. The distributions for sessions 7 and 8 also proved to be significantly different at the .0001 level, when compared with the Mann-Whitney U test.

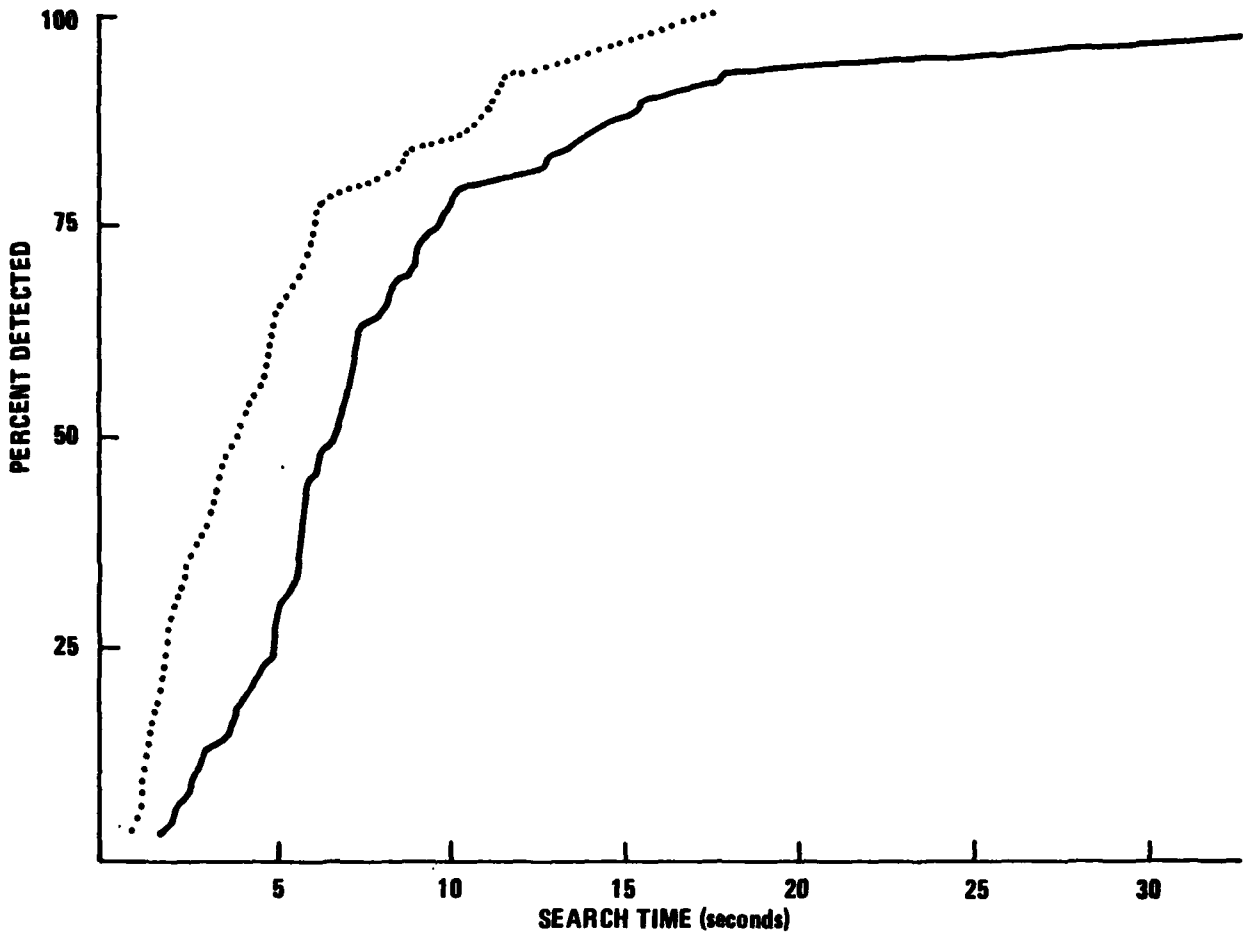

Figure 8. Cumulative distributions of search times for observer S14 searching for targets in the low ...., and medium ——, density regions of a two-region display, when the target is equally likely to be in either region: data from sessions 4, 5, and 6.

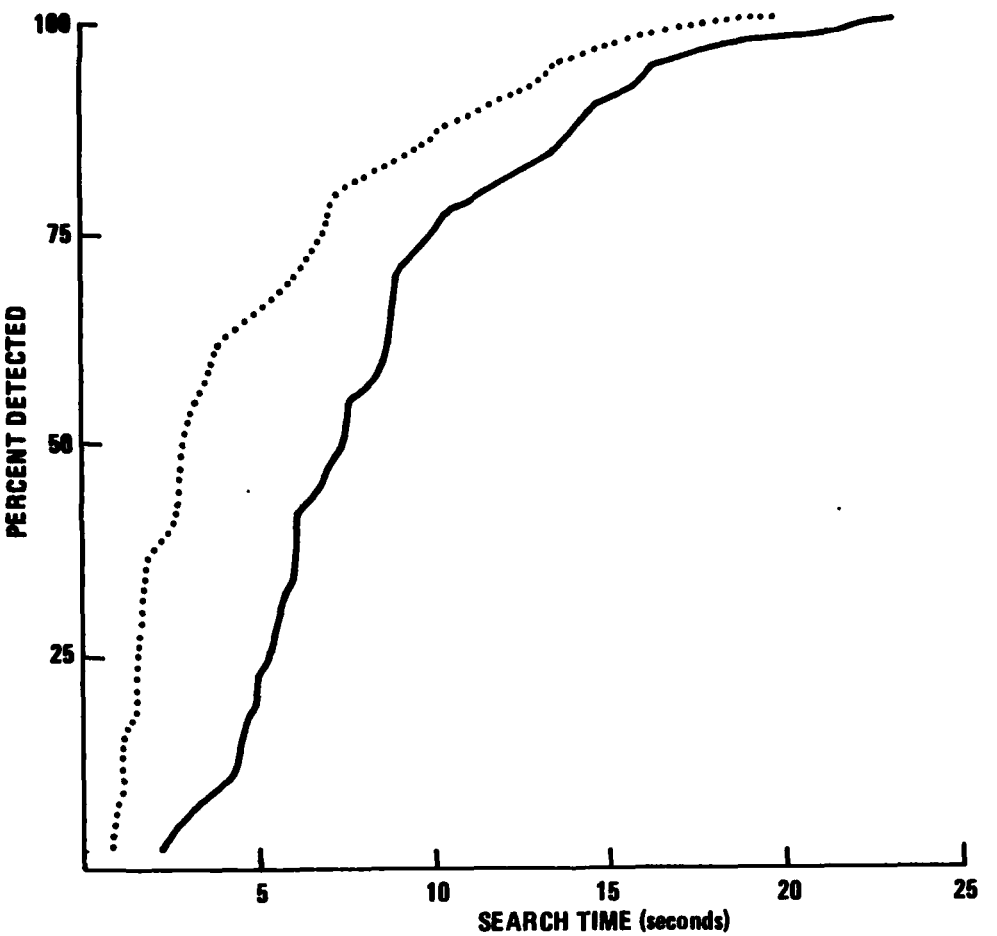

Figure 9. Cumulative distributions of search times for observer S14 searching for targets in the low...., and medium ____, density regions of a two-region display, when the target is equally likely to be in either region: data from sessions 7 and 8.

Discussion

A comparison of the data obtained from observers S13 and S14 on days 4-6 with their data on days 7-8 suggests the emergence of a different search strategy.

The fastest search time for a target in the low density region improved, from 0.98 to 0.82 seconds for S13 and from 0.91 to 0.76 seconds for S14. At the same time, the fastest search time for a target in the medium density region worsened, from 1.12 to 1.65 seconds for S13 and from 1.70 to 2.20 seconds for S14.

On days 4-6, observer S13 found only 3.3 percent of the targets located in the low density region before finding a target located in the medium density region. On days 7-8, 22.5 percent of the targets in the low density region were found before any were located in the medium density region. Similarly, for observer S14, the 20.0% of low density region targets found on days 4-6 before a target was located in the medium density region, increased to 37.5% on days 7-8.

The observers were beginning to conduct a relatively complete survey of the region in which targets were easier to find before switching to the more difficult medium density display.

EXPERIMENT 5: SEARCHING BOTH SIDES OF A TWO-REGION DISPLAY WHEN THE TARGET IS EQUALLY LIKELY TO REPLACE ANY NONTARGET IN EITHER REGION

This experiment is very similar to experiment 4, with the important distinction that in this case the target appeared more often in the medium density than in the low density region: the ratio of appearances was 63 to 20. Most other details of method and procedure were the same. The main points of difference are noted below.

Method

Four observers (S15, S16, S17, and S18) task part in this experiment. They were all between 20 and 22 years of age, and none of them had taken part in a search experiment before.

The target stimuli, display boards, apparatus and experimental set-up used in experiment 4 were used again.

Each observer was tested individually in six experimental sessions. The six sessions were treated as three two-session cycles for the purpose of determining which nontarget would be replaced by a target in each trial. In each two-session cycle, the target appeared once in each position: twenty times in the low density region, 63 times in the medium density region. It occurred ten times in the low density region in each session, five times in each half session. Within this constraint, the order in which the target positions were selected was randomized, without replacement. There were 20 trials in the first half-session of each cycle, and 21 in the remaining three half-sessions.

For this experiment, the observers were informed that the target had an equal chance of occurring in any of the 83 possible positions, and this was true even though there were more positions in one region than in the other.

As with Experiment 4, display No. 1 was used during the first half of the first session with low density randomly placed on the observer's right or left. In the middle of the session there was a ten-minute break, after which display No. 2 was used with the low density region on the opposite side to the first half session. The order of presentation of sides was counter balanced across sessions.

Each observer controlled the lights for the display and blank field and the electric timer with a switch, as in the previous experiment. Search times for correctly identified targets and false alarms were recorded.

Results

False Alarms. As with the previous experiment, the observers found it difficult to locate the target when it could be in either region when the two regions were of different nontarget density. Table 6 shows the percentage of false alarms that occurred in each session with each observer. The high initial rate for S16 dropped to a moderate level,

	Session					
Observer	1	2	3	4	5	6
S15	24	10	10	2	0	0
S16	24	29	10	12	7	10
S17	24	24	0	2	5	2
S18	7	0	0	2	0	0

Table 6: Percentage of false alarms occurring in each session with each observer

10%, for the last four sessions. It dropped even lower for S15 after three sessions, and S17 after two, while it was low for S18 virtually all the time.

Cumulative Search Time Distributions. The first two sessions of this experiment were treated as practice. Data from the remaining four sessions were combined, to produce cumulative plots of the time needed to locate targets in the low and medium nontarget density regions for each of the four observers.

On the basis of the cumulative plots, the observers can be divided into two groups, with S15 and S18 in one group and S16 and S17 in the other. Figure 10 shows the plots for S18. As it shows, the fastest seacrh times for targets in the medium and low density regions are similar. Then, the percentage of targets found in the low density region increases faster than the percentage located in the medium, with a maximum difference of about 25% occurring after seven or eight seconds (for S15 the maximum difference was 30% after four to five seconds). Then, the

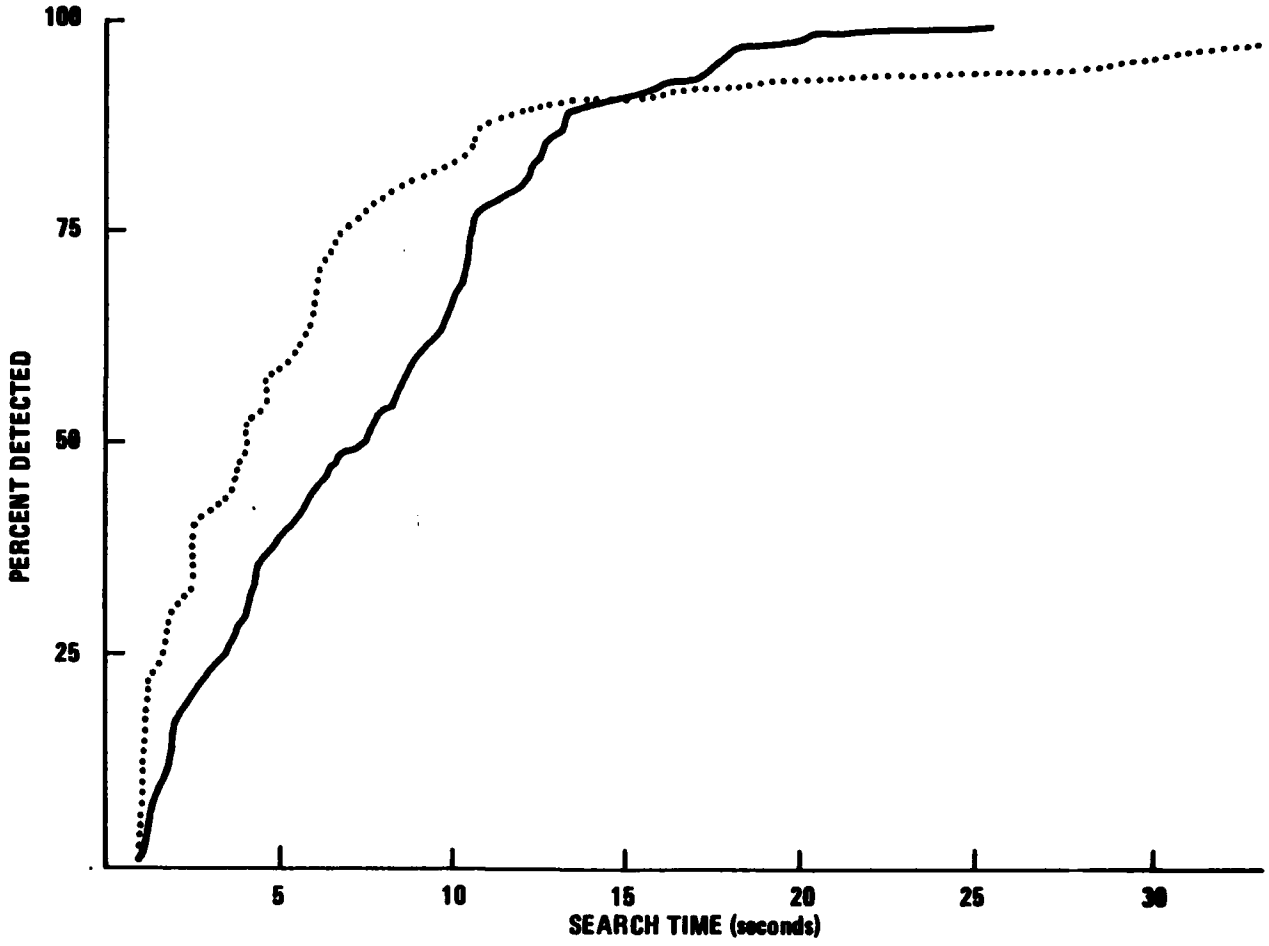

Figure 10. Cumulative distriubtions of search times for observer S18 searching for targets in the low ...., and medium ____, density regions of a two-region display, when the target is equally likely to replace each nontarget in the display.

percentage of targets found in the medium density regions increases faster than that for the low, with the result that the two distributions cross after about 15 or 16 seconds (16 or 17 seconds for S15).

Figure 11 shows the contrasting data of S16. For this observer, the two distribtuions gradually separate at first, but they do not come near each other again. There is no crossover. And this pattern was repeated by S17.

When the distributions obtained with the low and medium nontarget density regions were compared using the Mann-Whitney U test, they were found to be significantly different, at the .00003 for observers S16, S17, and S18, and at the .00016 level for observer S15.

Discussion

It appears from Figures 10 and 11 that two different approaches to searching the two-region display were adopted in this experiment. While neither approach involved concentrating exclusively on one region, S16 and S17 seem to have paid more attention to the low density region, while S15 and S18 paid more to the medium.

At first sight, it may seem that overall neither approach is superior to the other. For example, after 13 seconds, S16 has found an average of 77.5 percent of the targets (95 percent of those in the low region, and 60 percent in the medium) and S17 has found 75 percent (95 percent in the low, 55 percent in the medium), while, in the other group, S15 has found 72 percent (75 percent low, 70 percent medium) and S18 has found 90 percent (90 percent in both low and medium). These results seem roughly comparable, given that S18 performed best overall.

However, this view fails to take into account the fact a higher proportion of targets appeared in the medium density region (the ratio was 63 in the medium to 20 in the low). When this fact is considered,

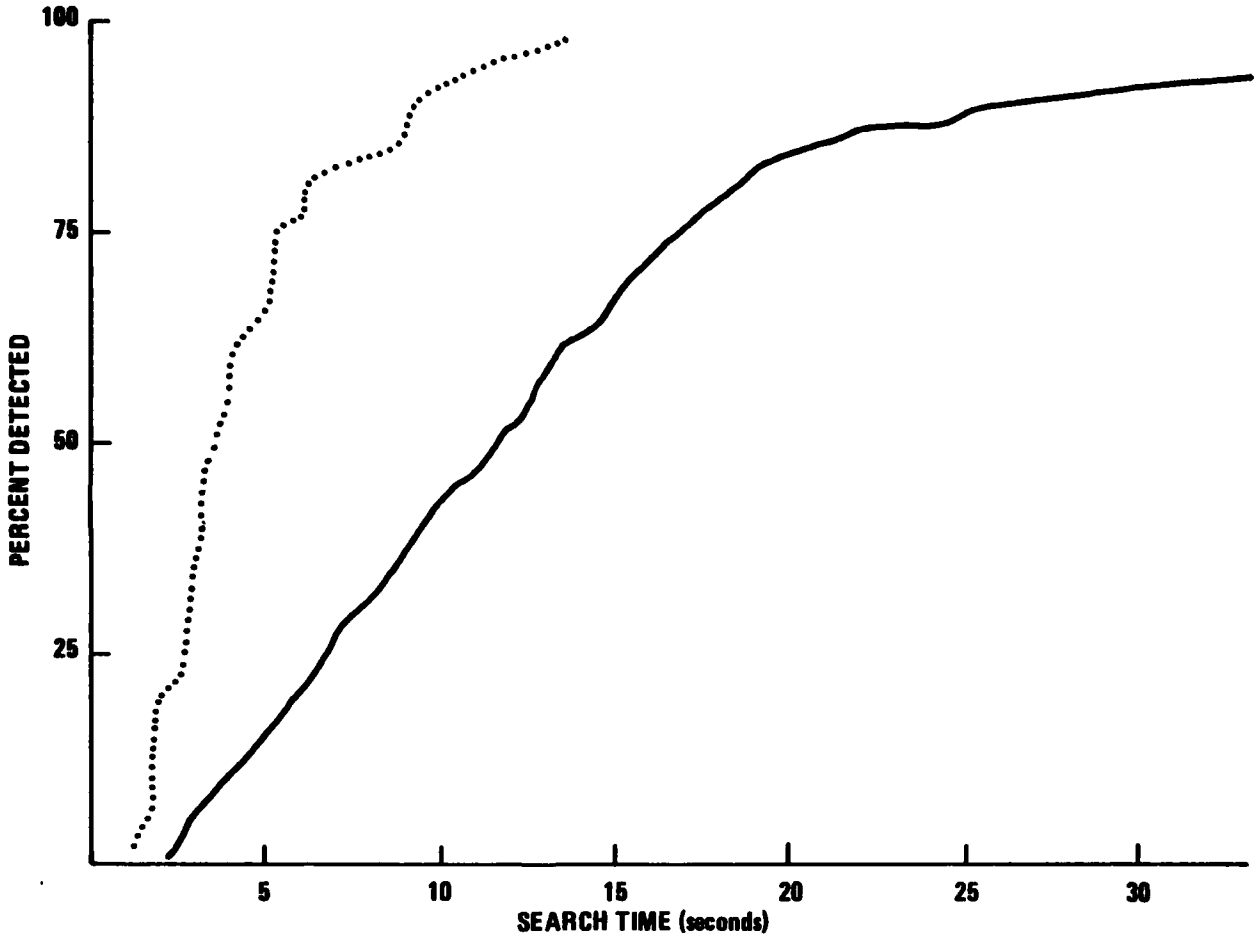

Figure 11. Cumulative distributions of search times for observer S16 searching for targets in the low ...., and medium ____ density regions of a two-region display, when the target is equally likely to replace each nontarget in the display.

the percentage of targets located on either side in the first 13 seconds of search is found to be 69 percent for S16, and 65 percent for S17. For S15, it drops only one point to 71 percent and, for S18, it remains at 90 percent. The approach of the latter pair of observers takes into account the fact that the target is equally likely to replace each nontarget, with the result that this approach tends to maximize the number of targets found quickly.

If the results of experiments 4 and 5 are taken together, it is clear that targets are found faster in a low density region than they are in a medium density region. When the probability of a target appearing in one region favors the low density region, observers gradually, over sessions, appear to adjust their strategy. When this probability favors the medium density region it seems harder to adjust: two observers did adjust, whereas the other two continued to pay more attention early in their search to the easier region even though it was less likely to contain the target.

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APPRENDIX

1

COMPARING VIEWING DISTANCE - DISCRIMINABILITY MEASURES WITH DIRECT ELECTRONIC FOURIER TRANSFORM (DEFT) 'CAMOUFLAGE' SPECTRA DATA.

Joe Hannigan of the U. S. Army Topographic Laboratories provided us with the three slides he used to produce 'camouflage' spectra data. Slide A shows a tank against a white background. For Slide B the same tank appears against a green background. This green background was also used for Slide C, but vegetation-like, clutter objects were added around on and around the tank.

We used these three slides in a maximum viewing distance experiment. Twelve observers were used. Seven were male and five were female. All had 20/20 vision or better (some with correction).

The slides were projected, one at a time, onto a screen. The screen was positioned at one end of a corridor. Before viewing each slide, each observer walked to the opposite end of the corridor. There, the observer turned and began to walk slowly toward the screen. The observer looked at the screen while moving toward it. When he or she was sure that he or she could tell that the object was a tank, the observer stopped. The distance between this stopping point and the screen was measured.

Next, the observer moved forward to a point maked on the floor. From there, he or she backed slowly down the corridor, looking all the time at the screen. This continued until the observer was sure that he or she could not tell that the object was a tank any longer. The distance from the screen at which this happened was also measured.

Each observer went through this procedure twice with each slide. Then a measure of maximum viewing distance was calculated. It was the average of the two distances obtained while the observer moved toward the screen and the two distances obtained when he or she moved away from it. The following table shows the averages for each observer for the three slides. The distances are measured in feet.

Observer	Slide A	Slide B	Slide C
1	27.75	21.97	11.02
2	29.32	23.29	6.79
3	45.56	28.73	14.94
4	70.18	38.36	15.85
5	37.87	32.64	15.50
6	44.79	28.00	15.80
7	42.21	27.77	14.07
8	14.35	11.94	5.00
9	29.63	22.93	14.41
10	70.83	36.70	18.95
11	56.49	34.77	12.85
12	57.02	33.99	10.74
Average	43.83	28.42	12.99

The DEFT spectra data, for these three slides, obtained by Joe Hannigan also provide measures of viewing difficulty. Arguing that Slide A shows the tank at its easiest to see, Joe Hannigan suggested that the differences in the spectra of Slides B and C from the spectra of A should be added (irrespective of sign) and used (expressed as a percentage of the total amplitude of Slide A) as a measure of the extent to which they were more difficult to see. Hannigan found that these measures agreed well with average ratings obtained from groups of observers.

We compared Hannigan's measures with the maximum viewing distance measures we obtained. The result is shown in the following table. Again Slide A was taken as the standard. The difference in viewing distance for Slides B and C, from the viewing distance for Slide A, is expressed as a percentage of the viewing distance for Slide A.

	DEFT MEASURE		VIEWING DISTANCE	
	Difference in db	Difference as %	Difference in Viewing Distance	Difference as %
Slide B	56	35.9	15.41	35.2
Slide C	112*	71.8	30.84	70.4

*NB This number is 2 db smaller than Hannigan's. He has an error in his calculation.

The very close agreement between the percentage differences obtained with Hannigan's DEFT device and those obtained in the current viewing distance experiment suggest that more rigorous testing is worthwhile.

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J. Wald
L. A. Thompson